Mechanism and Machine Theory 113 (2017) 179–192

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmachtheory

Research paper

# Type synthesis of tire building drum with scalable drum-shoulder

Heyu Liu, Fei Wang, Yuhu Yang*

*Key Laboratory of Mechanism Theory and Equipment Design of Ministry of Education, Tianjin University, Tianjin 300072, China*

ARTICLE INFO

*Article history:*
Received 1 June 2016
Revised 7 March 2017
Accepted 17 March 2017

*Keywords:*
Tire building drum
Axial and radial scalable
Type synthesis
Screw theory
Regenerative motion chain method

ABSTRACT

This paper deals with the innovative design of a tire building drum with large axial and radial scalable ratios. Type synthesis of the tire building drum with scalable drum-shoulder is studied by dividing the drum into internal and external drum-shoulder mechanisms according to movement requirements and driving modes. The possible structural forms of these two types of mechanisms are obtained by adding independent limbs. On that basis, the relationship of limb structural constraint screws is analyzed based on screw theory, resulting in the feasible structure of each limb subject to structural requirements, so that feasible initial configurations of the two types of mechanisms are obtained by combining the limbs. Thereby, the regenerative motion chain method is employed to obtain all the configurations with the same topological characteristics as initial configurations, during which 11 types of internal drum-shoulder mechanisms and 6 types of external drum-shoulder mechanisms are synthesized, respectively, and 726 types of tire building drums with scalable drum-shoulders are combined. Finally, the feasibility of the method proposed is corroborated with the CAD simulation model of one synthesized tire building drum.

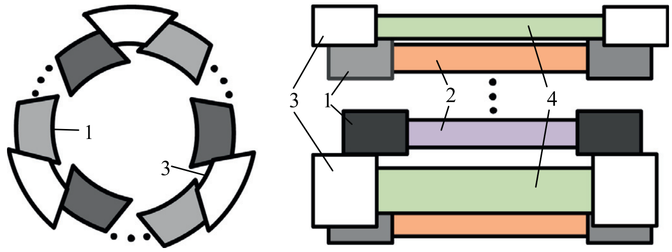

## 1. Introduction

Axial and radial scalable tire building drum, which is featured by large scalable ratio and wide forming range, is a kind of mechanism used for manufacturing aircraft tires or tires with high tire-sidewalls. Compared with simple radial scalable tire building drums [1–4], this kind of tire building drum is not only more complicated in structure, but also more difficult to be designed. Many literatures [5–10] have been focusing on the innovative design of this kind of mechanism, of which a typical example is the tire building drum with scalable drum-shoulder proposed by Roberts [11], whose contracted configuration forms a three-layer nested cylinder. Although large scalable ratio movement can be achieved by evenly distributed linkages along the circumference, it has been found that the slot cam fixed to the link only restricts the external drum-shoulder to move in the radial plane, but has no effect on the axial scalable movement [12]. Besides, the slot cam is a high-pair that requires high precision and is prone to be singular. Inspired by this discovery, we studied the type synthesis of this kind of tire building drum with scalable drum-shoulder to explore whether there is a better structure.

From the viewpoint of mechanism, this kind of tire building drum is composed of a group of linkages evenly distributed along a circumference, which belong to spatial multi-loop and multi-DOF mechanisms [13,14]. There are mainly three approaches available for the type synthesis of mechanisms, i.e. position orientation characteristics (POC) method [15,16], displacement subgroup [17–19], and screw theory [20–24], with which many multi-loop and multi-DOF mechanisms have been

* Corresponding author.
*E-mail address:* yangyuhu@tju.edu.cn (Y. Yang).

http://dx.doi.org/10.1016/j.mechmachtheory.2017.03.009
0094-114X/




(a) Axial view (b) Radial view

1-internal drum-shoulder; 2-internal segment; 3-external drum-shoulder; 4-external segment

**Fig. 1.** The general structure of tire building drum with scalable drum-shoulder.

synthesized. For example, YANG [16] obtained several new 3-DOF translational parallel robot mechanisms using Single-Opened-Chain (SOC) method; HERVÉ [18] studied the type synthesis of 3R2T 5-DOF parallel mechanisms by using Lie group and Lie algebras; ZENG [20] synthesized a series of spatial multi-loop coupled mechanisms based on displacement subgroup; KONG [21,22] proposed a method for type synthesis of parallel mechanisms based on virtual chain by using screw theory; HUANG [23,24] developed a systematic constraint screw synthesis method and synthesized 31 types of new lower-mobility parallel mechanisms. However, the limbs of the tire building drum with scalable drum-shoulder are not only complicated in structure, but also coupling with each other. Therefore, its type synthesis is more complex.

With the aid of screw theory [25–27], type synthesis of the tire building drum with scalable drum-shoulder is studied in this paper, aiming at providing a theoretical guidance for innovative design. The paper is organized as follows. In Section 2, analysis is carried out on the general structure of the tire building drum with scalable drum-shoulder, which is divided into internal and external drum-shoulder mechanisms. On that basis, possible types of the internal and external drum-shoulder mechanisms are respectively synthesized in Section 3. In Section 4, the combinations of two types of mechanisms are investigated, followed by the conclusions drawn in Section 5.

## 2. General structure of tire building drum with scalable drum-shoulder

### *2.1. Spatial distribution and movement requirements of the drum-shoulders*

The tire building drum with scalable drum-shoulder is a spatial scalable mechanism, which can simultaneously realize scalable motions along the axial and radial directions. As is shown in Fig. 1(a), its cylindrical shape remains the same in the process of expansion and contraction while the size of the cylinder varies. The circumferential surface is composed of a number of drum-shoulders and segments, which are evenly distributed along the circumference, as is shown in Fig. 1(b).

The drum-shoulder and the segment are connected by prismatic pair (P-pair), which can meet the axial movement requirement of the tire building drum. The finally expanded pose of this kind of mechanism is used for winding tire carcass, while the contracted pose is used for removing the tire. Therefore, all the drum-shoulders and segments should be able to form a cylindrical surface in the expanded pose in order to meet the requirements of the tire-sidewall shape and form a multi-layer nested cylinder in the contracted pose, as is shown in Fig. 2. The outside drum-shoulder and segment are named as external drum-shoulder and external segment, while the inside ones are named as internal drum-shoulder and internal segment (see Fig. 1).

To better clarify the shape-changing characteristics of tire building drum along the radial and axial directions simultaneously, the radial scalable ratio $i_{radial}$ and axial scalable ratio $i_{axial}$ are defined to describe the variations of radius and width along axial and radial directions, respectively, as is given in Eqs. (1) and (2).

$$i_{radial} = \frac{d_0}{d} \tag{1}$$

$$i_{axial} = \frac{L_0}{L} \tag{2}$$

where $d_0$ and $d$ represent the diameters, $L_0$ and $L$ represent the widths of tire building drum on the expanded and contracted poses, as is shown in Fig. 2.

The more layers the internal drum-shoulder nests, the larger the scalable ratio is, as is shown in Fig. 3. Therefore, the drum-shoulders should be shrunk into a three-layer nested cylinder in contracted pose. Thus, the internal drum -shoulder will be shrunk into a two-layer nested cylinder. To facilitate the analysis, the innermost internal drum-shoulder is named as inner layer drum-shoulder, and the second one is named as middle layer drum-shoulder, as is shown in Fig. 3.

In addition, in order to avoid the interference of layers, all the drum-shoulders should move in a plane during the movement process, as is shown in Fig. 4.